A Low-Cost Sensing System for Quality Monitoring of Dairy Products

Subhas Chandra Mukhopadhyay, *Senior Member, IEEE*, Chinthaka P. Gooneratne, Gourab Sen Gupta, *Senior Member, IEEE*, and Serge N. Demidenko, *Fellow, IEEE*

***Abstract*—The dairy industry is in need of a cost-effective, highly reliable, very accurate, and fast measurement system to monitor the quality of dairy products. This paper describes the design and fabrication works undertaken to develop such a system. The techniques used center around planar electromagnetic sensors operating with radio frequency excitation. Computer-aided computation, being fast, facilitates on-line monitoring of the quality. The sensor technology proposed has the ability to perform volumetric penetrative measurements to measure properties throughout the bulk of the product.**

***Index Terms*—Dairy products, interdigital type, meander, mesh, nondestructive testing, planar electromagnetic sensors, quality monitoring, sensing system.**

I. Introduction

DAIRY production is an important sector of the national economy of many countries in the world. For example, the national economy of New Zealand is significantly dependent on the export of dairy products; it is approximately 25% of the total foreign export earnings of the country. Currently, dairy industries in New Zealand employ the following procedure for analyzing and monitoring the quality of the milk—it measures the fat-to-protein ratio of milk using midinfrared spectroscopy prior to processing [1]–[6]. This provides a very accurate and rapid (1 reading/min) measurement with a standard deviation of 0.02% w/w from reference methods. In turn, it allows precise milk standardization, which is vital to efficient milk processing.

The infrared spectrometers used by large dairy companies in the world are very expensive. This makes it hard for small companies and individual farmers to use this technique to analyze the total solid content in milk. At the same time, such an analysis is very important because the dairy producers are paid based on the quality of their milk products. Hence, there is a need to develop a low-cost high-efficiency sensing system aimed at applications in the dairy industry. The use of an electromagnetic sensor has the potential to offer a good solution leading to a robust instrument with high accuracy at a low capital cost. At the same time, the testing system will be smart and light so that it can be carried easily to the testing site.

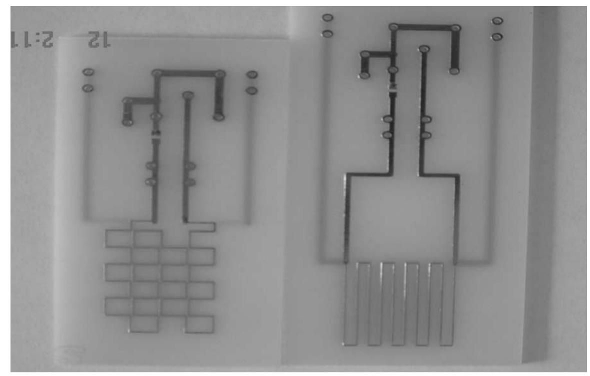
Manuscript received June 15, 2005; revised April 10, 2006.

S. C. Mukhopadhyay and C. P. Gooneratne are with the Institute of Information Sciences and Technology, Massey University, 5031 Palmerston North, New Zealand (e-mail: S.C.Mukhopadhyay@massey.ac.nz).

G. Sen Gupta is with the Institute of Information Sciences and Technology, Massey University, 5031 Palmerston North, New Zealand, and also with the School of Electrical and Electronic Engineering, Singapore Polytechnic, Singapore 139651.

S. N. Demidenko is with the School of Engineering, Monash University Malaysia, Selangor 46780, Malaysia.

Digital Object Identifier 10.1109/TIM.2006.876541



(a) (b)

Fig. 1. Planar electromagnetic sensors. (a) Mesh configuration. (b) Meander configuration.

The current system, which is based on infrared spectrometry, is heavy and is not flexible at all to do the test; the milk sample has to be sent through the test rig.

Electromagnetic sensors are widely used in various fields of modern technology and engineering. One of the examples of such areas is the detection of defects in the printed circuit board and the estimation of near-surface material properties of conducting and magnetic materials [7]–[12]. This sensing technique has the potential to be successfully employed in the quality inspection of dairy products such as milk, butter, cheese, curd, and yogurt. The objective of this paper is to design and develop a high-performance, low-cost, and real-time smart sensing system for quality monitoring of dairy products.

The technique discussed here is based on the use of a planar electromagnetic sensor operating with radio frequency (RF) excitation. It is supported by fast computer-aided computations, which allow real-time monitoring of the product quality. The sensing system is cost effective and highly reliable both in terms of measurement accuracy and speed of measurement. Furthermore, the sensor has the ability to perform volumetric penetrative measurements to evaluate properties throughout the product.

The operating principle of the electromagnetic sensing technique is introduced in Section II. The results of our initial investigation using the planar sensors on different dairy products are detailed in Section III. In Section IV, we present our low-cost sensing system and compare the performance of various types of planar sensors, namely the mesh, meander, and interdigital types. The details of the techniques used for the analysis of test data are summarized in Section V.

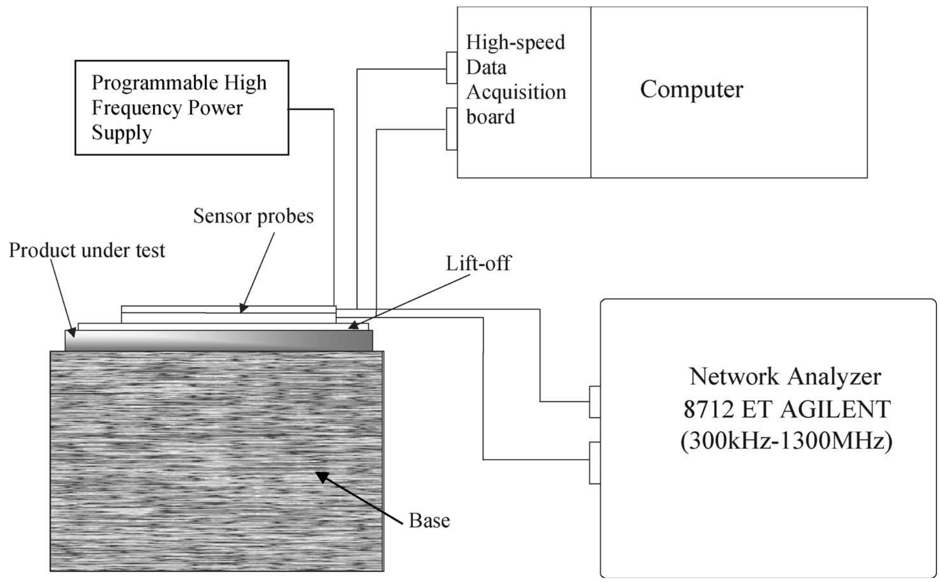


Fig. 2. Block diagram representation of the experimental setup.

II. Operating Principle of the Electromagnetic Sensing Technique

The planar electromagnetic sensors, which have been used for the inspection of material properties, are of two different configurations, namely 1) meander and 2) mesh. Fig. 1 shows the fabricated sensors of the meander and mesh types used for that purpose. One of the earlier applications was the inspection of inner layer cracks or defects of the printed circuit board of the Pentium processor [7]. The inspection and evaluation of the system properties is carried out without destroying them. The use of the planar sensors has been extended to inspection of metal and electroplated materials [8]–[12].

Nondestructive evaluation techniques are able to detect the presence of cracks, discontinuities, mechanical fatigue, and many other problems without material damage. This has resulted in increased application of these techniques in recent times. It has been demonstrated that the mechanical stress has the ability to change the electrical properties (for example, electrical conductivity) [13]. This can be used as an index of mechanical fatigue.

The planar electromagnetic sensing technique employing RF signal is based on the interaction between the measurement signal and the product under investigation. The sensor consists of two coils. The first coil (which is known as exciting coil and carries RF signal) generates an electromagnetic field. The generated electromagnetic field interacts with the nearby materials being measured. The resultant electromagnetic field is measured by the second coil of the sensor, which is known as the pickup coil. It is placed above the exciting coil, which makes both the exciting and sensing coils at the same side of the sample under test. The ratio of the voltage of the pickup coil to the current of the exciting coil is defined as the transfer impedance. The voltage applied across the exciting coil is v_1.

The current due to the applied voltage, i.e., the exciting current is i_1.

The voltage across the sensing coil is v_2.

The transfer impedance is defined as

$$Z = \frac{v_2}{i_1}. \tag{1}$$

The transfer impedance is measured in a complex form. It is a function of many parameters such as permittivity, conductivity, and permeability of the material being measured, liftoff, operating frequency, and thickness. The details of the analytical calculation of finding transfer impedance have been described in [11]. It is possible to calculate the transfer impedance with a given frequency, coil structure, and material properties, i.e., the conductivity, permeability, and permittivity of the nearby materials. However, the problem under consideration is an inverse problem in which material properties are of interest from the given transfer impedance. There is no direct method available to determine the material properties separately. However, it is possible to evaluate the material properties with the help of some computational methods. As a result, it is possible to monitor the quality of the material under investigation (in our case, dairy products like milk and cheese) by means of measurement of its properties, in particular, the value of permittivity.

III. Experimental Setup and Preliminary Investigation

The block diagram representation of the experimental setup is shown in Fig. 2. For the meander- and mesh-type sensors, high frequency of excitation is usually used for the inspection of dielectric materials because it enables higher variation of the impedance values. The actual experimental setup is shown in Fig. 3. In the current experimental setup, a network analyzer (Agilent 8712ET with the frequency range of up to 1.3 GHz) was used to carry out the experiments. In the final product, the analyzer was replaced by a low-cost system.

A very comprehensive set of experiments have been carried out. Some of the most interesting results of these experiments

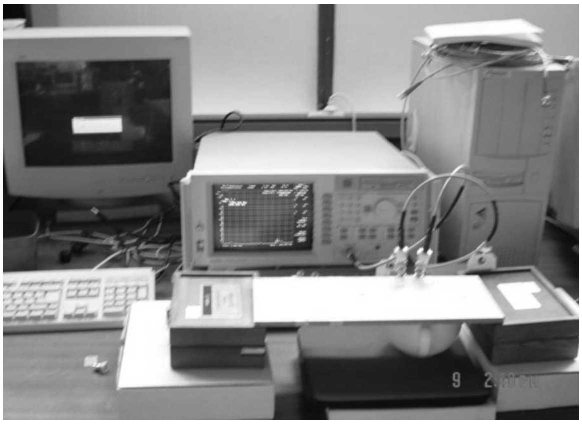


Fig. 3. Actual experimental setup based on network analyzer.

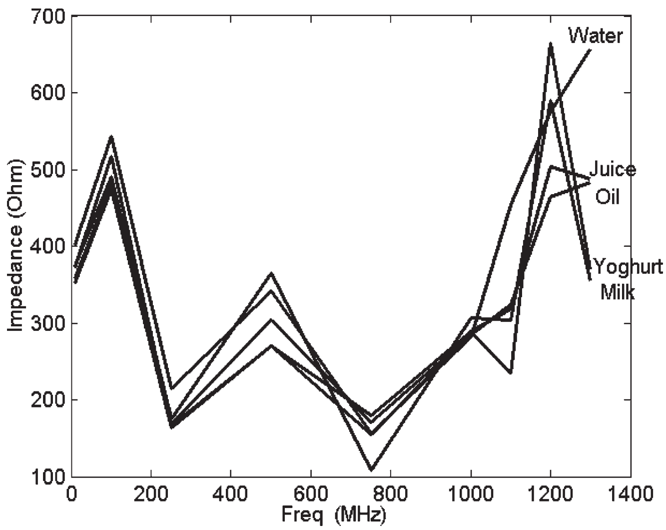


Fig. 4. Impedance magnitude as a function of frequency for different dielectric materials.

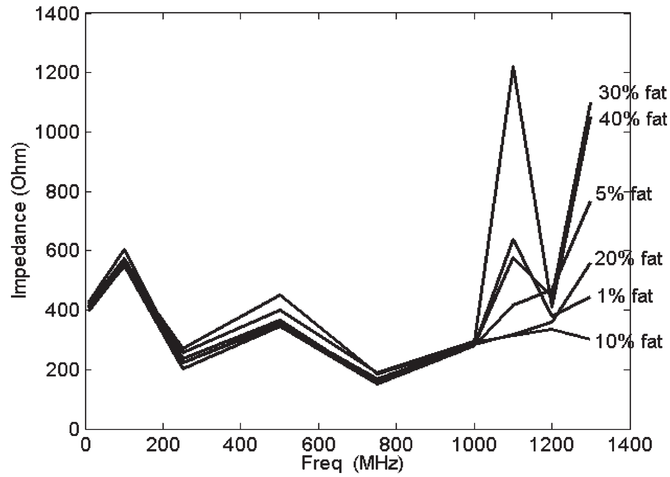


Fig. 5. Impedance magnitude as a function of frequency for milk with different fat contents.

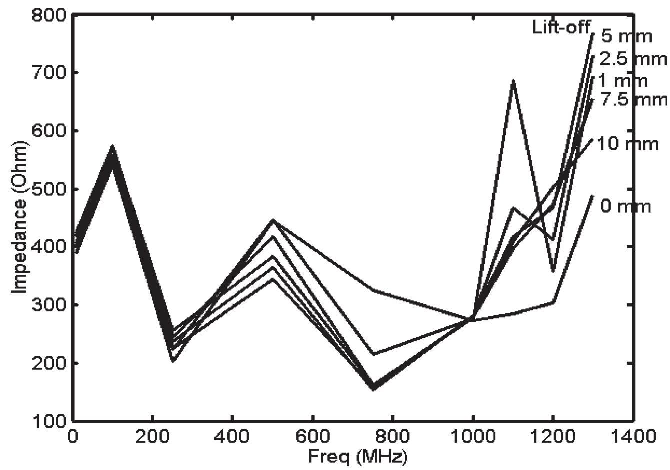


Fig. 6. Impedance magnitude as a function of frequency for milk with different liftoffs.

are presented in this section. Fig. 4 shows the variation of impedance with frequency for different products such as water, fruit juice, milk, oil, and yogurt. The variation of impedance with frequency is not smooth due to a few experimental data as the values are measured at every 100 kHz. Moreover, there is no curve fitting used while the data are plotted. It can be seen from the results that the impedance is different for different products. This is due to the fact that different products have different effective permittivities. At high frequency of operation, the sensors are responsive to dielectric permittivity. These experiments have been carried out by employing planar mesh-type microelectromagnetic sensor, which shows much better response compared with the meander types.

To examine the usefulness of the proposed sensor in the dairy industry, milk samples with known percentage of fat content were prepared in the laboratory, and the effect of the fat content on the impedance was examined. Fig. 5 shows the variation of impedance with frequency for different percentages of fat content.

Fig. 6 presents the variation of impedance with frequency for milk with different liftoffs.

Both the magnitude and phase of the transfer impedance have to be used to find the equivalent permittivity of the product under test. It can be seen from the experimental results that different amounts of fat causes considerably different readings.

The operating frequency of the sensor is one of the most important parameters that help achieve the best possible resolution. Thus, the right selection of the operating frequency is very important. Fig. 7 shows the variation of impedance with different percentages of fat content for an operating frequency of 750 MHz, which provided very good resolution, at a liftoff of 5 mm. It can be seen that the fat content has an appreciable effect on the transfer impedance of the sensor.

IV. Low-Cost Sensing System

Due to the use of costly network analyzer, the current setup is quite expensive and not affordable by small-scale industries and farmers. Several possibilities have been explored for the development of a low-cost smart sensing system. The following areas are identified:

1) sensors;
2) excitation system;
3) data acquisition system.

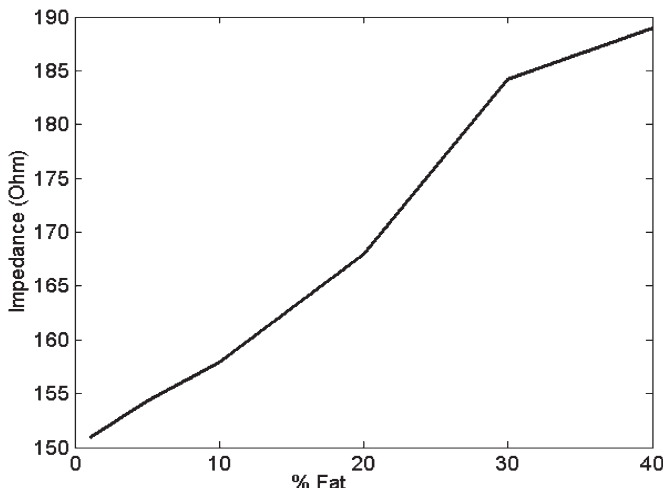


Fig. 7. Variation of impedance with percentage of fat content at 750 MHz with 5-mm liftoff.

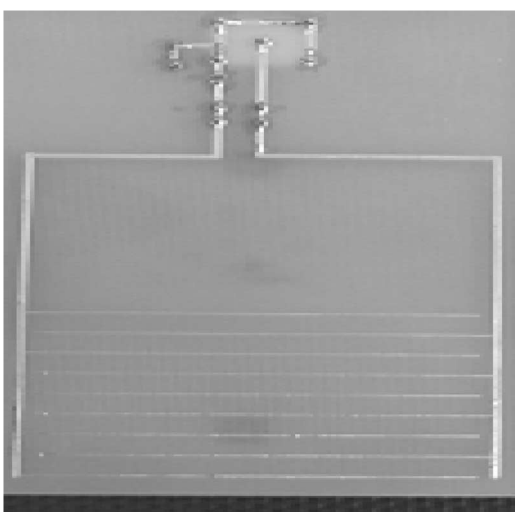


Fig. 8. Electromagnetic sensors of interdigital configuration.

Because the currently used planar mesh-type sensor exhibits good response to milk product at a relatively high frequency, the necessary excitation and data acquisition systems are expensive. To obtain moderate response at a low frequency of operation, another type of planar sensor has been investigated.

A. Sensors

The sensors are basically the heart of any inspection system. The sensors giving very good response at a relatively low frequency are very important for the development of a low-cost sensing system. To explore the possibility of using sensors at low frequencies, a planar sensor of interdigital configuration, as shown in Fig. 8, has been considered. The characterization and comparative performance evaluation of all three planar electromagnetic sensors, namely 1) meander; 2) mesh; and 3) interdigital, have been performed. All of them are suitable for a nondestructive inspection and evaluation of product properties.

Different sizes of sensors of each meander, mesh, and interdigital types have been experimented with using the experimental setup shown in Fig. 9. The sensor has been connected to a high-frequency supply while the voltage across and the current through the sensor are being recorded. For the characterization of the sensors and to study their comparative performance, the frequency of excitation has been varied between 100 kHz and 100 MHz. The impedance characteristics of the sensors are shown in Figs. 10–12, respectively. It is seen that the transfer impedance for both the meander and mesh types increases with the increase in frequency, whereas the impedance of the interdigital-type sensor decreases with frequency. For the same effective area, the response of the mesh-type sensors is better than the meander type. Basically, meander- and mesh-type

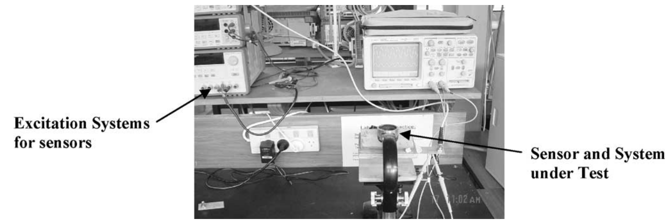


Fig. 9. Experimental setup for sensor characterization.

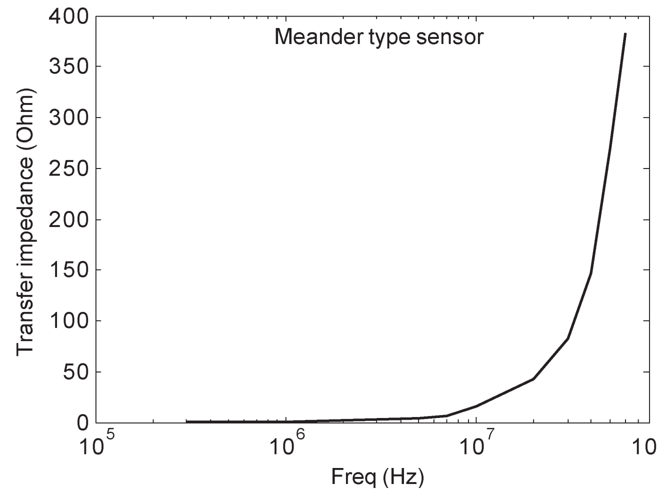


Fig. 10. Transfer impedance characteristics of the meander-type sensor.

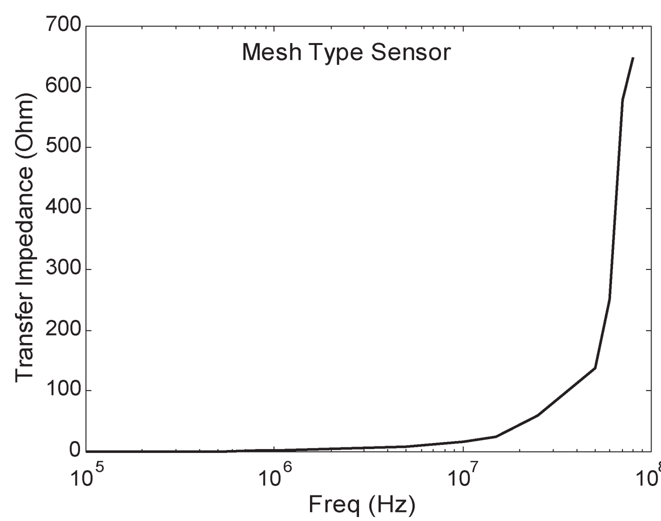


Fig. 11. Transfer impedance characteristics of the mesh-type sensor.

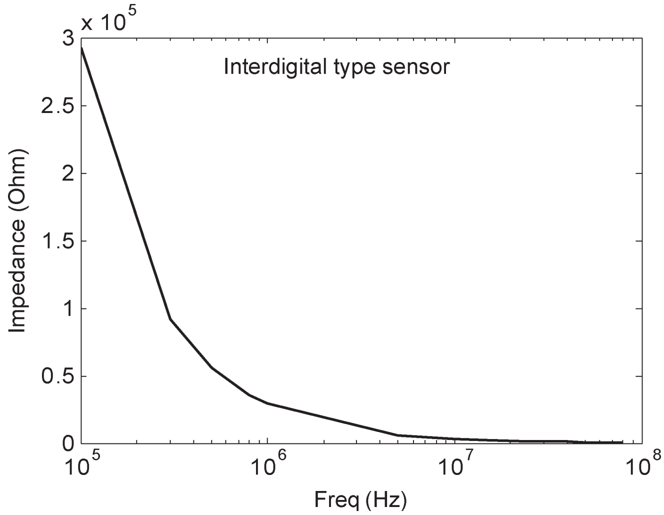


Fig. 12. Transfer impedance characteristics of the interdigital-type sensor.

sensors are inductive type, whereas the interdigital-type sensor is capacitive type. It is also seen that both meander- and mesh-type sensors respond well at high frequencies. The response of the interdigital sensor is very good at low frequencies and does not respond well at high frequencies. Thus, the operating frequency has to be very carefully selected.

B. Excitation System

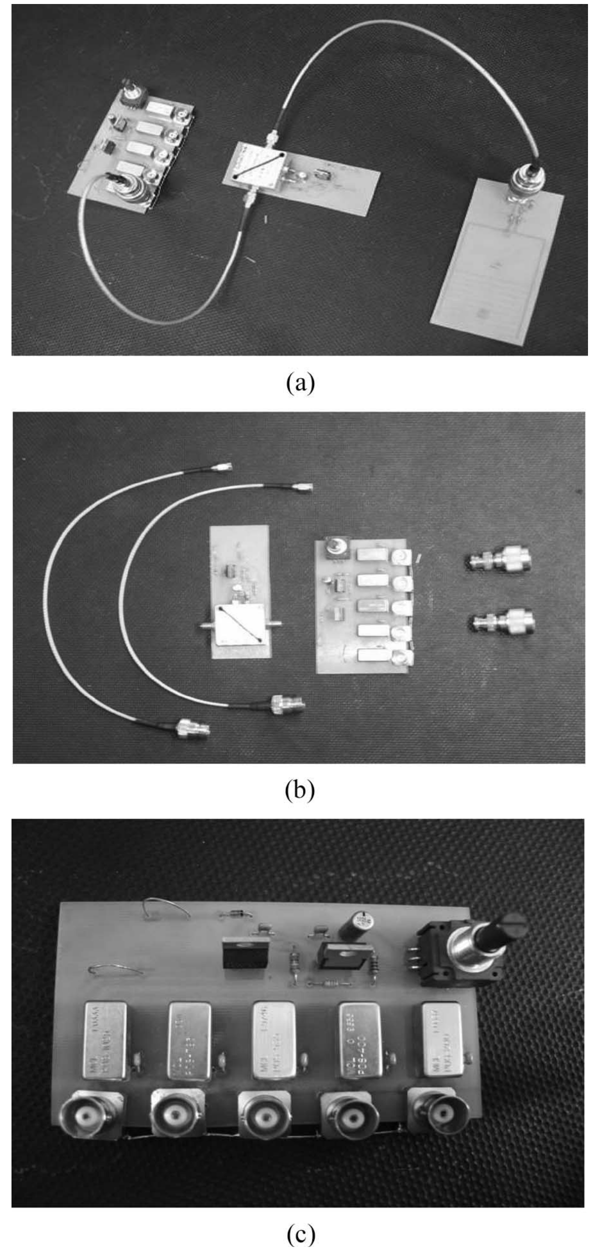
A smart power supply and associated instrumentation to provide the controlled excitation to the exciting coil of the sensor is very important for target development. A controlled variable frequency power supply has been designed and developed for the supply of excitation voltage. The frequency can be controlled from tens of kilohertz to 1 GHz. The important components of the system are briefly discussed here.

Fig. 13(a) shows the sensor connected to the power supply. Fig. 13(b) shows the different components of the power supply unit. The total frequency range has been obtained by switching between different voltage-controlled oscillators (VCOs) corresponding to different frequency ranges. Fig. 13(c) shows the VCO unit of the power supply.

The graph in Fig. 14 depicts the tuning voltage versus the VCO operating frequency. The graph corresponds to one of the VCOs used to generate the exciting signal feeding the power amplifier. The straight dash line shows an ideal characteristic. It can be seen that the actual characteristic (solid line) is not too far from the ideal one.

The output of the power amplifier is connected to all the sensors, and the effect of different materials in close proximity of the sensors is observed. Table I shows the experimental results for all the sensors at an operating frequency of 84 MHz. Only the amplitude change of the sensor output signal is shown in the table. However, in practice, the phase information will also be used.

It can be observed in Table I that the meander- and mesh-type sensors respond very well to conducting and magnetic materials (i.e., copper, aluminum, and iron). However, their reaction to dielectric materials is not as good. On the other hand,



(a) (b) (c)

Fig. 13. Sensors and instrumentation. (a) Sensor with power supply. (b) Power supply unit. (c) VCO unit.

the interdigital sensor acts in an opposite manner and responds well to dielectric materials. Thus, the interdigital-type sensor has been chosen for the monitoring of dairy products. Fig. 15 shows a comparative response of all the three types of sensors at an operating frequency of 100 kHz. The interdigital-type sensor is very responsive to the change of fat content of milk.

C. Data Acquisition System

For the collection of voltage and current signals, an efficient data acquisition system is very important. The analog data is captured using an analog-to-digital converter (ADC). A Silicon Lab microcontroller C8051F020 has been considered at the first instant. The SiLab C8051F020 has two ADCs operating at 100 and 500 kHz, respectively. Hence, an operating frequency of up to 50 kHz can be very well used using this system. The

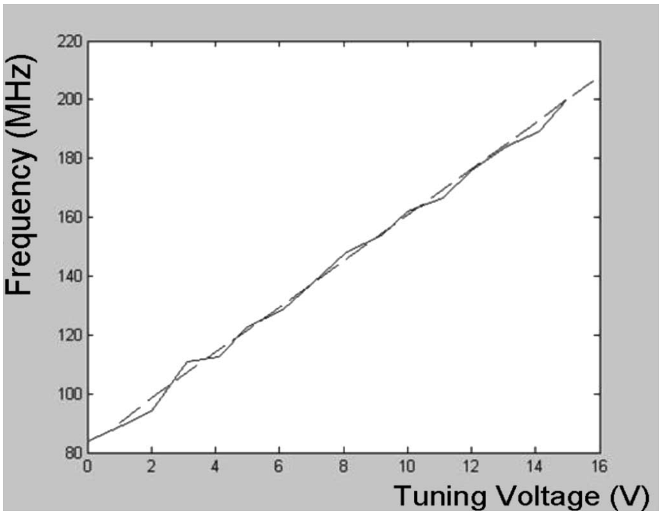


Fig. 14. Frequency as a function of tuning voltage.

TABLE I
SENSOR EXPERIMENTAL RESULTS

System Under Inspection	Sensor Output Amplitude Change at 84 MHz		
	Meander	Mesh	Interdigital
Air	1	1	1
Copper	0.9127349	0.8764259	1.0151976
Aluminum	0.9118998	0.8669202	1.0151976
Iron	0.9077244	0.7742395	0.9984802
Milk	1.0205952	0.9697908	0.9022801
Water	1.0188946	0.9733264	0.9251887

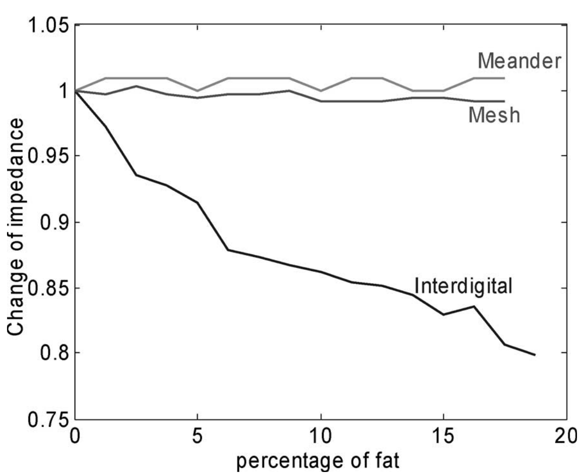


Fig. 15. Response of three types of sensors to the fat content of milk at 100 kHz.

block diagram representation of the system is shown in Fig. 16. The system has already been developed and used; it provides good results for a single-frequency measurement as shown in Fig. 17.

V. ANALYSIS OF THE EXPERIMENTAL RESULTS

The experimentally obtained data were analyzed with the use of a special computational technique to determine the composition of dairy products. The technique is based on either a single-frequency or a multiple-frequency excitation.

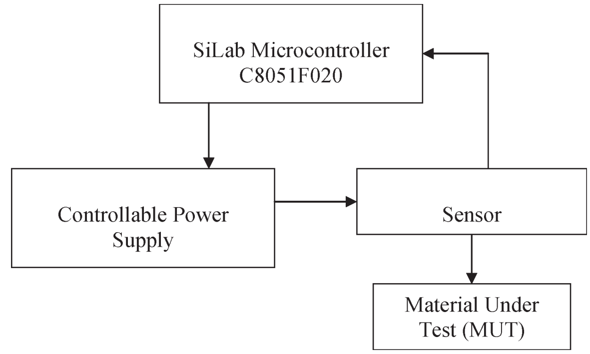


Fig. 16. Block diagram representation of the microcontroller-based system.

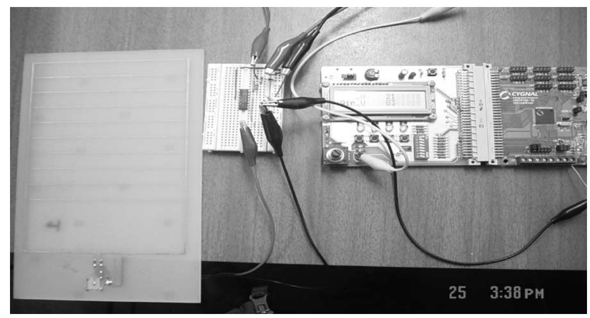


Fig. 17. Data acquisition system based on SiLab microcontroller C8051F020.

The technique related to the single-frequency excitation system is the polynomial curve fitting. Only the magnitude of the impedance was used, and the fat content was measured, providing results with an error less than 1%.

To determine the composition of a milk product using a multifrequency excitation method, the following technique was proposed. Let us assume that a product has n components with X_n percentage each so that $\sum X_n = 1$. The experimental results are collected for n times at n different frequencies. From each measurement, the resultant relative permittivity is calculated. The resultant permittivity can be expressed as

$$\varepsilon_{r1,1}X_1 + \varepsilon_{r2,1}X_2 + \varepsilon_{r3,1}X_3 + \cdots + \varepsilon_{rn,1}X_n = \varepsilon_{\text{res},1} \quad (2)$$

where $\varepsilon_{r1,1}, \varepsilon_{r2,1}, \ldots, \varepsilon_{rn,1}$ are the relative permittivity values of each component at the chosen frequency and are known.

As a result, after n readings, the following matrix equation is obtained:

$$\begin{bmatrix} \varepsilon_{r1,1} & \varepsilon_{r2,1} & \varepsilon_{r3,1} & \cdots & \varepsilon_{rn,1} \\ \varepsilon_{r1,2} & \cdots & \cdots & \cdots & \varepsilon_{rn,2} \\ \varepsilon_{r1,3} & \cdots & \cdots & \cdots & \varepsilon_{rn,3} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \varepsilon_{r1,n} & \varepsilon_{r2,n} & \varepsilon_{r3,n} & \cdots & \varepsilon_{rn,n} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} \varepsilon_{\text{res},1} \\ \varepsilon_{\text{res},2} \\ \\ \vdots \\ \varepsilon_{\text{res},n} \end{bmatrix}. \quad (3)$$

Using the matrix representation, the following expression can be written:

$$\mathbf{A} \times \mathbf{X} = \mathbf{B} \quad (4)$$

where $\mathbf{B}$ is the matrix obtained from the experimentally measured resultant permittivity values, and $\mathbf{A}$ is the matrix known from the dielectric permittivity versus the frequency

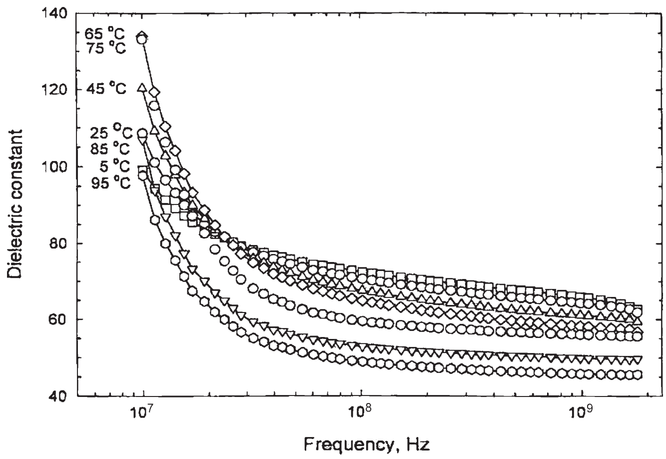


Fig. 18. Typical characteristics of dielectric permittivity as a function of frequency.

characteristic of each component. Usually, the dielectric permittivity is a function of temperature and operating frequency. A typical frequency- and temperature-dependent dielectric permittivity characteristics of a fruit sample is shown in Fig. 18 [14], [15]. To determine the $\mathbf{X}$ matrix of (4), the permittivity values, i.e., the elements of $\mathbf{A}$ matrix, can be stored in the computer. From the experimental measurement, $\mathbf{B}$ is obtained. $\mathbf{X}$ can be calculated by solving (4).

VI. Conclusion

The electromagnetic sensor-based approach proposed in this paper can be a very promising alternative to the existing measurement techniques used in the dairy industry to monitor product quality. This sensing technique is nondestructive in nature. It is also safe and cost effective. In addition, the approach does not involve any fragile sensing elements (such as glass probes), and it is quite stable (requires only infrequent periodic calibration).

The effect of dielectric materials such as milk, butter, cheese, curd, and yogurt on the transfer impedance of planar electromagnetic sensors has been experimentally observed and is reported in this paper. It is shown that the properties of dielectric materials have a great influence on the value of the transfer impedance. The experimental results also showed that the sensor had a very good potential to be used to determine the composition of dairy products. The transfer impedance can be used to determine the quality of the product by using the developed computation technique.

The reported investigation has opened up a very good possibility of incorporating the technique into the dairy industry. By monitoring the quality of the product, the proposed sensor system would be able to contribute to the improvements of the production process and waste reduction as well.

References

[1] F. R. Van de Voort, "Fourier transform infrared spectroscopy applied to food analysis," *Food Res. Int.*, vol. 25, no. 5, pp. 397–403, 1992.

[2] D. Firestone and A. Sheppard, "Determination of trans fatty acids," in *Advances in Lipid Methodology*, vol. 1. Bridgwater, U.K.: Oily, 1992, pp. 274–289.

[3] D. Lefier, R. Grappin, and S. Pochet, "Determination of fat, protein and lactose in raw milk by Fourier transform infrared spectroscopy and by analysis with a conventional filter-based milk analyser," *J. AOAC Int.*, vol. 79, no. 3, pp. 711–717, 1996.

[4] A. Hewavitharana and B. Van Brakel, "Fourier transform infrared spectrometric method for the rapid determination of casein in raw milk," *The Analyst*, vol. 122, no. 7, pp. 701–704, Jul. 1997.

[5] F. R. Van De Voort, K. P. Menon, J. Sedman, and A. A. Ismail, "Determination of solid fat for index by Fourier transform infrared spectroscopy," *J. Amer. Oil Chem. Soc.*, vol. 73, no. 4, pp. 411–416, 1996.

[6] F. R. Van De Voort, J. Sedman, G. Emo, and A. A. Ismail, "Assessment of Fourier transform infrared analysis of milk," *J. Amer. Oil. Chem. Assoc.*, vol. 75, no. 5, pp. 780–785, 1992.

[7] S. Yamada, H. Fujiki, M. Iwahara, S. C. Mukhopadhyay, and F. P. Dawson, "Investigation of printed wiring board testing by using planar coil type ECT probe," *IEEE Trans. Magn.*, vol. 33, no. 5, pp. 3376–3378, Sep. 1997.

[8] S. C. Mukhopadhyay, "Quality inspection of electroplated materials using planar type micro-magnetic sensors with post processing from neural network model," *Proc. IEE—Sci., Meas. Technol.*, vol. 149, no. 4, pp. 165–171, Jul. 2002.

[9] S. C. Mukhopadhyay, S. Yamada, and M. Iwahara, "Experimental determination of optimum coil pitch for a planar mesh type micro-magnetic sensor," *IEEE Trans. Magn.*, vol. 38, no. 5, pp. 3380–3382, Sep. 2002.

[10] ——, "Optimum coil pitch selection for planar mesh type micro-magnetic sensor for the estimation of near-surface material properties," *JSAEM Stud. Appl. Electromag. Mech.*, vol. 14, pp. 1–9, 2003.

[11] S. C. Mukhopadhyay, "A novel planar mesh type micro-electromagnetic sensor—Part I: Model formulation," *IEEE Sensors J.*, vol. 4, no. 3, pp. 301–307, Jun. 2004.

[12] ——, "A novel planar mesh type micro-electromagnetic sensor—Part II: Estimation of system properties," *IEEE Sensors J.*, vol. 4, no. 3, pp. 308–312, Jun. 2004.

[13] Y. Shi and D. Jiles, "Finite element analysis of the influence of a fatigue crack on magnetic properties of steel," *J. Appl. Phys.*, vol. 83, no. 11, pp. 6353–6355, Jun. 1, 1998.

[14] S. O. Nelson, "Frequency and temperature dependence of the dielectric properties of fresh fruits," in *Proc. 5th Int. Conf. Electromagn. Wave ISEMA*, Roturua, New Zealand, Mar. 23–26, 2003.

[15] S. O. Nelson and P. G. Bartley, "Measuring frequency-and temperature-dependent permittivities of food materials," *IEEE Trans. Instrum. Meas.*, vol. 51, no. 4, pp. 589–592, Aug. 2002.

Subhas Chandra Mukhopadhyay (M'97–SM'02) was born in Calcutta, India, in 1965. He received the B.Eng. degree (with a gold medal) from the Department of Electrical Engineering, Jadavpur University, Calcutta, in 1987, the M.E.E. degree from the Indian Institute of Science, Bangalore, India, in 1989, the Ph.D. degree in engineering from Jadavpur University, in 1994, and the Dr.Eng. degree in electrical engineering from Kanazawa University, Kanazawa, Japan, in 2000.

From 1989 to 1990, he was with the Department of Research and Development, Crompton Greaves Ltd., Mumbai, India. In 1990, he joined the Department of Electrical Engineering, Jadavpur University, as a Lecturer and was promoted to Senior Lecturer in 1995. After obtaining a Monbusho fellowship, he went to Japan in 1995 and worked with Kanazawa University as a Researcher and an Assistant Professor until September 2000. In September 2000, he joined the Institute of Information Sciences and Technology, Massey University, Palmerston North, New Zealand, as a Senior Lecturer, where he is currently an Associate Professor. He has published 148 papers in different international journals and conferences, authored a book and a book chapter, and edited five conference proceedings. His research interests include electromagnetics, control, electrical machines, and numerical field calculation.

Dr. Mukhopadhyay is a Fellow of the Institution of Electrical Engineers (IEE) and an Associate Editor of the IEEE Sensors Journal.

Chinthaka P. Gooneratne received the B.Eng. degree in information and telecommunication engineering and the M.Eng. degree in electromagnetics from Massey University, Palmerston North, New Zealand, in 2004 and 2005, respectively.

He has published ten papers in different international journals and conference proceedings. His research interests include electromagentic sensors, modeling, and characterization.

Gourab Sen Gupta (M'89–SM'05) received the B.E. degree in electronics from the University of Indore, Indore, India, in 1982, and the M.E.E. degree from Philips International Institute, Eindhoven, The Netherlands, in 1984. He is currently working toward the Ph.D. degree in intelligent control of multiagent collaborative systems at Massey University, Palmerston North, New Zealand.

He was with the Consumer Electronics Division, Philips India, Pune, India, as a Software Engineer for five years. In 1989, he joined the School of Electrical and Electronic Engineering, Singapore Polytechnic, Singapore, where he is currently a Senior Lecturer. He is also a Visiting Senior Lecturer with the Institute of Information Sciences and Technology, Massey University. His current research interests include embedded systems, real-time vision processing, behavior programming for multiagent collaboration, and automated testing and measurement systems.

Serge N. Demidenko (M'91–SM'94–F'04) received the M.E. in electrical engineering degree from the Belarusian State University of Informatics and Radio Electronics, Minsk, Belarus, in 1977 and the Ph.D. degree in electrical engineering from the Belarusian Academy of Sciences, Minsk, in 1984.

While in Belarus, he progressed from being an Engineer to the Head of the Joint (Industry–Academy) Test Laboratory of a large electronic manufacturing company and held Head-of-the-Department positions in the academia and industry. He was an Academic Staff of higher learning institutions of several countries. He is currently the Deputy Head and Chair of the School of Electrical and Computer Systems Engineering, Monash University, Selangor, Malaysia. He is an author of four books and more than 80 papers and is the holder of 25 patents. His research interests include electronic design and test, fault tolerance, and signal processing.

Dr. Demidenko is a Fellow of Institution of Electrical Engineers (IEE) and a U.K. Chartered Engineer. He is an Associate Editor of *JETTA: Journal of Electronic Testing: Theory and Applications* and the IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT. He is a Co-Chair of TC-32 of the IEEE I&M Society, a member of the Board of Directors of IMTC, and the Chair of the IEEE I&M Malaysia Chapter.

A low-cost sensing system for quality monitoring of dairy products

Mukhopadhyay, S. C.

2006-08